AN AUTOMATIC RECORDING B-H METER

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ABSTRACT. An automatic recording B —H meter operating on 220 V, 50 c.p.s. has been constructed. The hysteresis loop is observed on the screen of a C.R.O. from which informations regarding its magnetic properties e.g. coercive force, magnetic induction etc. can be obtained.

The present paper describes the construction and working of the B —H meter, also some test measurements on carbon steel, high speed steel and magnetite are given.

INTRODUCTION

In connection with the choice of proper indigeneous materials for the construction of cores of electromagnets and development of various magnetic instruments and apparatus in this country, a detailed knowledge of the usual ferromagnetic properties of these materials is essential. Hence a programme for the development of techniques for quick and quantitative measurement of B—H curves at different temperatures was undertaken by the authors. Various methods for the purpose have been adopted by Crittenden *et al* (1951), Howling (1956) and others. But the balancing and calibrating systems of their methods are very complicated and the results obtained are not always free from uncertainties.

We have therefore constructed an automatic hysteresis loop tracer wherein the balancing and calibrating systems have been made much simpler and with which we could obtain quick and accurate information regarding saturation magnetisation, coercive field, hysteresis loss, residual induction and saturating field at different temperatures of any ferromagnetic material in convenient size and shape.

Demand for the construction of such an instrument also came from the workers of this laboratory studying ferromagnetism of naturally occuring single crystals to enable them to obtain preliminary informations on curie temperature, saturation induction etc. The present paper describes such a B—H meter working at 50 c.p.s. with provisions for observations at different temperatures in the range of 90°K to 1000°K.

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WORKING PRINCIPLE OF THE INSTRUMENT

If an a.c. voltage is applied to the primary of n turns of a mutual inductance system with a magnetic core in which magnetisation I is produced, then a voltage v is produced in the secondary of N turns, given by

$$v = NA\left(\omega H_0 \cos \omega t + 4\pi \frac{dI}{dt}\right) \times 10^{-8} \text{ volts} \qquad \dots \quad (1)$$

where A is area of the core and H_0 is the peak field produced inside the primary and the rest of the symbols have their usual significances.

If the voltage in the secondary before the introduction of the core, given by the first term in (1), is eliminated by balancing, say, by putting another secondary connected in opposition then the additional voltage $NA\, 4\pi \frac{dI}{dt} \times 10^{-8}$ develops in the secondary on introduction of the core. This voltage after proper integration will evidently furnish us with a value directly proportional to the magnetisation of the material of the core. If this voltage after integration and a voltage proportional to the magnetising field are simultaneously fed with proper phase-relationship to the y- and x-plates respectively of a C.R.O., a trace of hysteresis loop will be obtained.

DESCRIPTIONS OF THE INSTRUMENT

The instrument essentially consists of :

a) Two primary magnetising coils (m.c.)

b) Two secondary coils (s.c. and b.c.)

c) Amplifying and integrating units

d) The cathode ray oscilloscope.

a) *Primary magnetising coils*

The alternating magnetic field is produced by the two primary magnetising coils (m.c.), wound on brass spools, each having about 1150 turns of 22 S.W.G. super enamelled copper wire. Average diameter of each coil is 8.2 cms. and length is about 3.2 cms. The two coils are placed coaxially at a distance of 3.5 cms. from each other. The two coils are connected in series and fed by current from 220 volts, 50 c.p.s. power mains. A drop of voltage accross a resistance (R) placed in this circuit is fed to the horizontal plates of the C.R.O.

b) *Secondary coils*

Each of the secondary coils consists of 1700 turns of 36 S.W.G. super enamelled copper wire wound on brass spools of 2.5 cms. in length and an average diameter of about 6.5 cms. One of these (s.c.) is placed coaxially with the primaries and in the gap between the two primary coils and the other (b.c.) similarly at one end

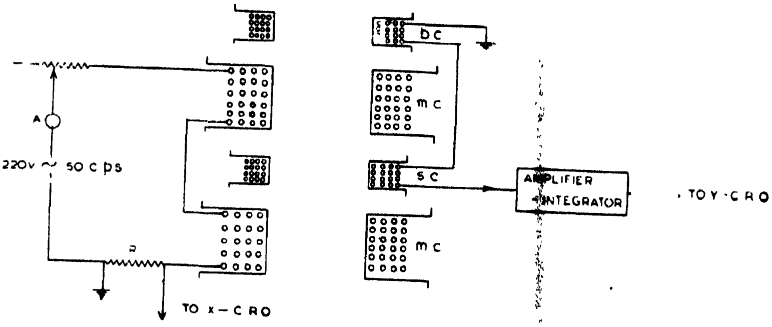

Fig. 1. A schematic diagram of the hysteresis loop tracer.

of the magnetising coils. These two secondary coils are connected in opposition so that when there is no ferromagnetic sample inside the coil (s.c.) the output voltage is zero. The output side of the two secondaries in opposition being connected, through an amplifier and an integrator, to the y-plates of the C.R.O., there should only be a horizontal trace on C.R.O. even with the full gain of the amplifier so long as the voltage of the two secondary coils are completely balanced.

When the sample is introduced inside the secondary coil (s.c.) in between the two primaries, the vertical deflection that is now observed in the C.R.O is only due to the sample and is obviously proportional to its magnetisation I. The two, the vertical and the horizontal deflections, combine to trace the hysteresis loop.

An auxiliary coil (a.c.) of 50 turns is wound over the secondary coil (s.c.) for calibration of the y-axis. The method of calibration etc. are described in a subsequent section.

c) *The Amplifier and the Integrator*

The output voltage of the secondary being usually very small and after time integration only a small part of this being available it becomes necessary to amplify it suitably. Required amplification is obtained by using a high gain tube. It is so selected as to have a high plate resistance (r_p). For integration, the plate load is shunted by a capacitance, so that at the working frequency (50 c.p.s.) the plate load is almost capacitative the time constant being almost one second.

In our case a single stage amplifier using a 6 SJ 7 vacuum tube operating at 90 volts from battery has been utilised. However successive stages may be added whenever, higher gains are desired.

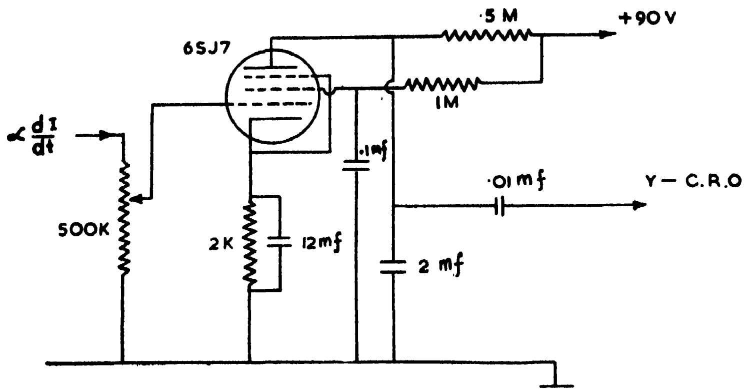

Fig. 2. The amplifier and the integrating circuit.

The disposition of the different parts of the apparatus, can be best followed from the block diagrams 1 and 2.

CALIBRATION

In order to obtain quantitative information regarding the various ferromagnetic constants from the trace of the loop on C.R.O., calibration of its y and x axes which as already indicated are proportional to I and H, is essential.

Magnetic field Calibration (x-Calibration).

If i' amps. r.m.s. current flows through the two magnetising coils, and the magnetic field produced in the gap between the two coils is H', then

$$H' = H'_0 \sin \omega t$$

H'_0 being the peak value of the a.c. magnetic field. The corresponding voltage V induced in the secondary coil (s.c.) of area of cross section A sq. cm. will be

$$V = NA \frac{dH'}{dt} \times 10^{-8} \text{ volts}$$

$$= NA\omega H'_0 \cos \omega t \times 10^{-8} \text{ volts}$$

and the average value of V is given by

$$\bar{V} = NA\omega \left| \frac{H'_0}{\sqrt{2}} \right| \times 10^{-8} \text{ volts} \qquad \dots (2)$$

Knowing this voltage $\bar{V}$, H_0' can be determined and (H_0'/i') peak field per ampere r.m.s is also correspondingly known.

Thus for any current i amperes r.m.s the peak value of the magnetic field H_0 is given by

$$H_0 \quad i\left(\frac{H_0'}{i'}\right) \tag{3}$$

The resistive voltage drop due to various currents across a fixed resistance R, placed in the magnetising circuit, when fed to the x-plates of C.R.O. produces proportional horizontal traces. The magnetic field correspondingly produced will therefore be proportional to these x deflections.

Therefore magnetic field H_0 corresponding to deflection x will be $H_0 = kx$ where k is the constant of proportionality, which can be obtained from a separate experiment as suggested by the relations (2) and (3). From an actual experiment we have found $k = 50$ oersted/cm.

Calibration for Magnetisation (y-Calibration)

A sample of cross section α sq. cm. when placed in the magnetic field in between the two magnetising coils will, as stated earlier, induce a voltage v in the secondary, given by

$$v = 4\pi\alpha N \frac{dI}{dt} \times 10^{-8} \text{ volts}$$

Let this voltage give a vertical deflection y on C.R.O. after necessary amplification and integration so that

$$4\pi\alpha NI \times 10^{-8} \times C = y \quad \ldots \quad (4)$$

where C is a constant.

Now a small voltage due to induction in the auxiliary coil (a.c.), having a small number of turns n, due to the same magnetising a.c. field H'_0 is fed to the amplifier and the integrator and from there to the y plates of C.R.O. and a trace y' is obtained (without any sample inside) on C.R.O. then,

$$n\,a\,H'_0 \times 10^{-8} \times C = y' \quad \ldots \quad (5)$$

where a is the area of cross section of the auxiliary coil. Then from (4) and (5) we have

$$I = y\left(\frac{n\,a\,H'_0}{y' 4\pi\alpha N}\right).$$

For a field of 254 oersted, which has generally been used for calibration and the corresponding deflection 1.5 cm., the above expession reduces to

$$I = 4.65\frac{y}{\alpha},$$

It may be mentioned in this connection that in order to study the temperature variation of the ferromagnetic properties of different materials, the lower portion of a narrow tailed dewar incorporating a low temperature cryostat or a tubular electric heater with a water jacket around it can easily be introduced inside the primary of the system.

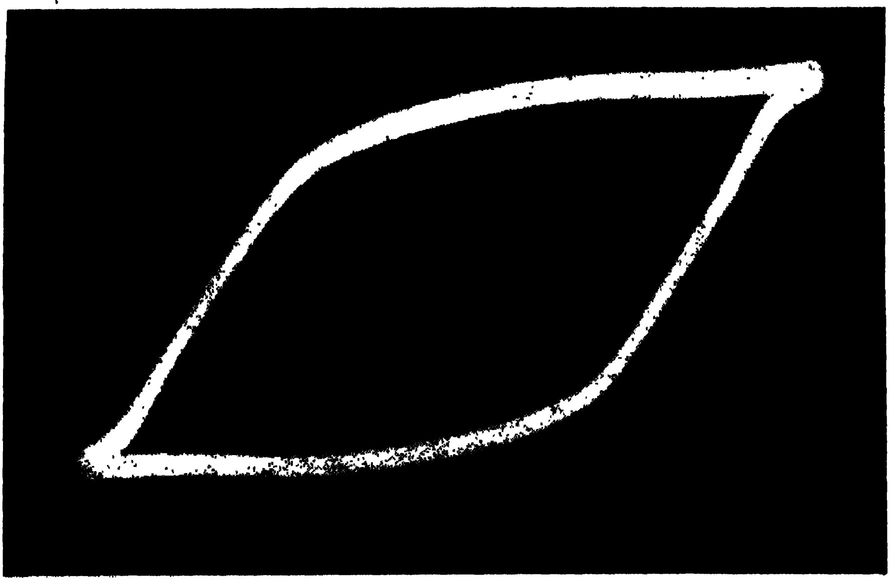

Fig. 3. Hysteresis loop of carbon steel.

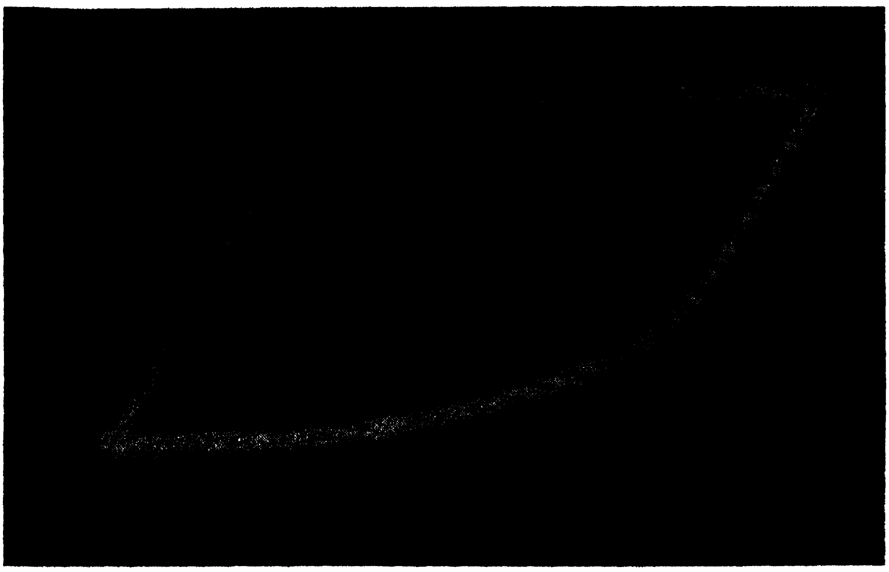

Fig. 4. Hysteresis loop of high speed steel.

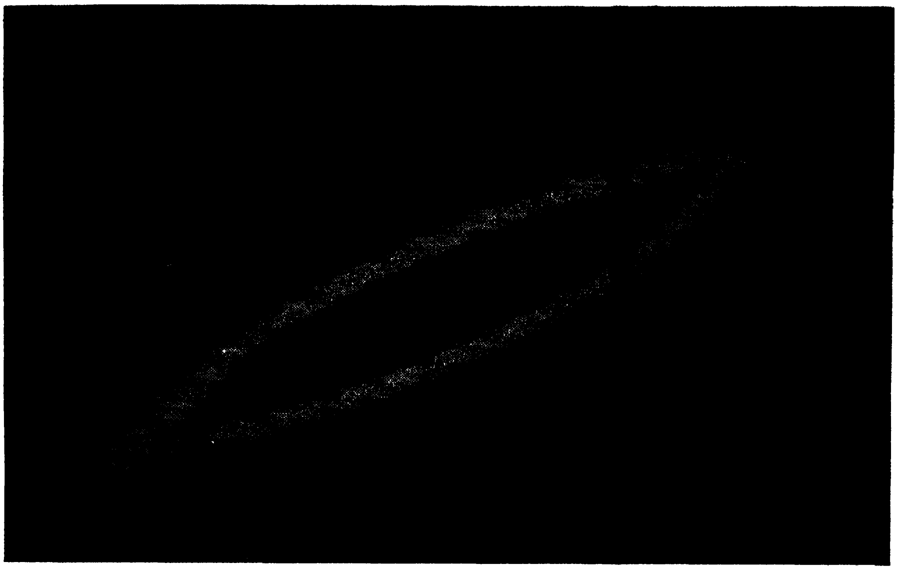

Fig. 5. Hysteresis loop of magnetite.

SOME TEST OBSERVATIONS

Some observations have been recorded for test purposes with carbon steel and high speed steel, both of which were supplied from our workshop. Observation have also been recorded with single crystals of magnetite. The C.R.O. traces are shown in figure 3, 4 and 5 and the values in the adjoining tables(I and II). It is to be noted here that the maximum field available (400 gauss) in the present instrument though sufficient to saturate the various grades of ferrous materials is not enough to do so in case of ferromagnetic minerals as in case of magnetite. However, in case of magnetite the value of magnetisation for any particular field as obtained fom the C.R.O. trace is the same as obtained from measurements with a sensitive magnetic balance for the corresponding field. We are now engaged in modifying the instrument so that higher fields may be obtained sufficient to saturate almost all ferromagnetic crystals.

TABLE I

	Carbon Steel		High speed Steel	
	Present observer	Reported (Bozorth, 1951)	Present observer	Reported (Bozorth, 1951)
Saturation Magnetisation (in c.g.s units)	800	not available	600	not available
Residual Magnetism (gauss)	650	830	480	860
Coercive force (in gauss)	110	50	90	70
Hysteresis loss, ergs/cycle	45,000	not available	30,000	not available

Though the observations agree in order yet they differ from absolute values. This is due to small variation in composition and difference in history.

TABLE II

Magnetite

Field	Magnetisation from C.R.O. trace	Magnetisation from measurements with magnetic balance done in this laboratory
400 oersted	150 c.g.s.	145 c.g.s.

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